ce 6d.

Geological Series
Bulletin No. 5

UNION OF SOUTH AFRICA

DEPARTMENT OF MINES

THE
ICKEL-COPPER OCCURENCE
IN THE
Bushveld Igneous Complex West of the Pilandsbergen

A PRELIMINARY REPORT

BY

C. M. SCHWELLNUS, B.Sc.

PUBLICATION OF THE GEOLOGICAL SURVEY DIVISION

THE GOVERNMENT PRINTER, PRETORIA
1935

S.4209—27/5/35—1,500

Geological Series
Bulletin No. 5

UNION OF SOUTH AFRICA

DEPARTMENT OF MINES

THE NICKEL-COPPER OCCURENCE IN THE Bushveld Igneous Complex West of the Pilandsbergen

A PRELIMINARY REPORT

BY

C. M. SCHWELLNUS, B.Sc.

PUBLICATION OF THE GEOLOGICAL SURVEY DIVISION

THE GOVERNMENT PRINTER, PRETORIA
1935

.P.-S.4209—27/5/35—1,500

TABLE OF CONTENTS.

FIGURES IN THE TEXT.

The Nickel-Copper Occurrence in the Bushveld Igneous Complex, West of the Pilandsbergen.

A PRELIMINARY REPORT.

Introduction.

The following report is based upon an examination of the property of the South African Minerals, Ltd., and the surrounding country situated in the Pilansberg area, about 38 miles north-west of the town Rustenburg.

The period of investigation started in March, 1934, and intermittent short visits were paid to the mine during the months of July and October, 1934. The writer is at present preparing a detailed geological map of the area in which the nickel deposits have so far been located. This report is a preliminary one based on the data on hand. A detailed description of the rocks is not yet available. These have been identified from hand specimens unless otherwise mentioned.

Acknowledgments.

I wish to express my indebtedness and gratitude to Mr. S. Chudleigh for accommodation and every possible assistance during my investigation. I am very thankful to Mr. J. H. Paul, the late Mr. A. L. Chambers, and all the members of the technical staff of the mine for their always ready assistance.

My gratitude also goes to Dr. D. L. Scholtz of the University of Pretoria who has placed his collection of Sudbury nickel ores, and also ores of various other nickel mines, at my disposal; and also for his ever ready and friendly scientific advice which I always found very helpful.

The valuable assistance of my colleagues has always been highly appreciated.

General.

The farms Vlakfontein No. 902 and Groenfontein No. 302 are at the two extremities of a broad zone of basic rocks in which the gossans are distributed. The direction of the zone is in a broad curve which roughly parallels the outer fringe of the Pilandsbergen, and is about three to four miles away from it on the farms Vlakfontein No. 902, Bakhoutrandje No. 1039 and Tweelaagte No. 180, while towards the north, on the farm Groenfontein No. 302 the distance increases to about five miles. Groenfontein No. 302 is situated about fifteen miles north of Vlakfontein No. 902.

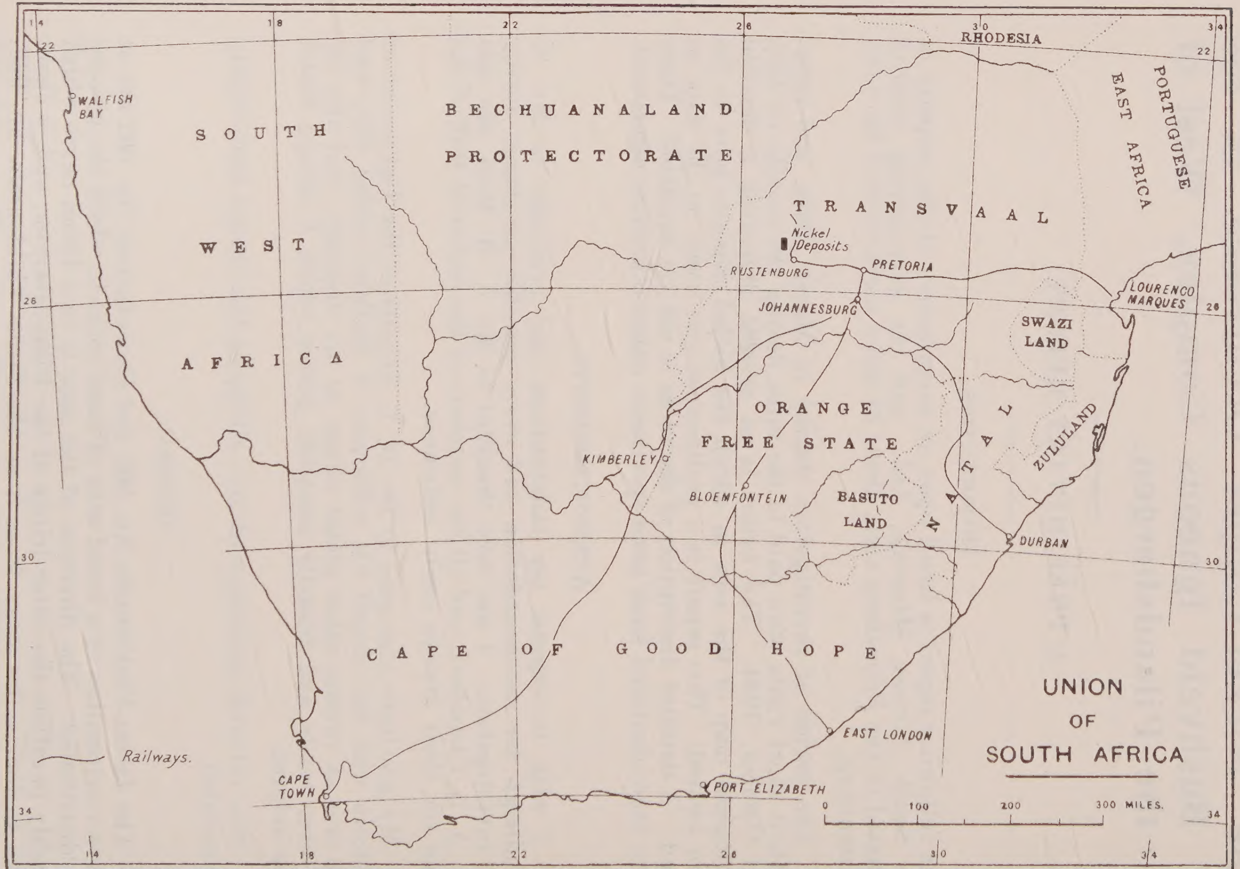


Fig. 1.—Outline Map of the Union showing Locality of Deposits.

The gossans do not seem to follow a straight line or a narrow zone, but are distributed over a broad stretch covered chiefly by turf with scanty grass and thornbush. The area is drained by a few intermittent rivers.

Every gossan so far opened up has proved that the opaline gossan eventually merged into sulphides at about 40 to 50 feet down, and in rare cases sulphides were encountered about 20 feet below the surface. Such gossans have been explored to ore-bearing depths on the farms Vlakfontein No. 902, Vlakfontein No. 305 and Groenfontein No. 302. The evidence obtained from such widespread different gossans suggests that all existing gossans can reasonably be looked upon as caps over ore bodies, the extent of which will have to be proved by future mining development.

For the sake of centralisation the company's mining activities are at present confined to their freehold portion of Vlakfontein No. 902.

History.

In 1910 the late Mr. S. C. Harding, a very able prospector, started sinking on these gossans and opened up four ore bodies. Mr. S. Chudleigh was the inspirer and financial supporter who kept the prospecting going after intermittent abandonment. To-day the mine has been brought almost to the producing stage. Plant has been bought and is now being erected, and the Vlakfontein mine will most probably start producing before the end of 1935.

Previous Work.

The nickel deposits of Vlakfontein have been the topic of various discussions amongst geologists and mining engineers in the past, and none seems to have agreed with Wagner on the point of the genesis of the ore.

In the *S.A. Journal of Industries* of 1918 T. G. Trevor, then Inspector of Mines, gave a brief but accurate description of the Vlakfontein deposits. He gave a short description of the No. I, II, III and IV shafts, the available ore in situ and its average copper and nickel content. He expressed the opinion of an obvious similarity between the conditions under which the nickel is found on Vlakfontein and in the Sudbury area. The author mentioned that it was extremely unfortunate " that prospecting should have stopped where it did, and if only one shaft were continued for a couple of hundred feet below waterlevel some definite result would have been obtained ".

J. A. Ortlepp published a paper in 1922 entitled: " Investigations on the Copper-Nickel Ores of the Rustenburg District ". Ortlepp examined polished sections and identified most of the minerals so far known to occur in the Vlakfontein deposits, and also ascribed the origin of the ore to a process of magmatic differentiation. Ore concentration tests were carried out and the direct matte smelting from the handpicked ore was found to be the only suitable one. This conclusion has also been reached by Prof. G. H. Stanley who reported on the Vlakfontein ores from the metallurgical point of view in 1921 and 1927.

Wagner's Memoir 21 on " Magmatic Nickel Deposits of the Bushveld Igneous Complex ", published in 1923, is undoubtedly the most detailed report ever given out on this occurrence of nickel. The author gives a description of the Bushveld Complex with special reference to the norite zone, and a detailed petrographic, mineralogical, geological and economic description of Vlakfontein. Wagner believes the ores to be deposits of a magmatic segregation in situ and also expresses the opinion that graphite, associated with the ore, might be responsible for the localisation of the ore bodies.

Robert D. Hoffmann published a paper in the *Journal of Economic Geology* of 1931. He pointed to the fact that since the completion of Wagner's report more underground work, giving additional facilities for making more complete observations, has revealed conditions which throw new light on the origin of these deposits. Hoffmann showed that pipe-like ore bodies, vertical in character, display typical replacement structure and are equally developed in the harzburgite and bronzitite across which the ore bodies cut. In short, he pointed out that the ore-structure is at right angles to the rock-structure, and that the ore bodies were intruded after the consolidation of the rocks and were formed by agencies which came from below. Pre-existing fractures are responsible for the localisation of the ore bodies.

E. R. Schoch published in the *South African Mining and Engineering Journal*—26th January, 1929, an interesting report describing the Vlakfontein deposits and pointed out that the theory of origin of " magmatic segregation in situ " advanced by Wagner is untenable. He suggested that pneumatolysis was a more likely explanation of ore genesis and that the Pilandsberg Intrusive may have had some genetic connection with the nickel deposit. The shape and perpendicular position suggest that a deep-seated concentrated sulphide mass, under stress of great pressure and heat, aided by the eruptions of the Pilandsberg, would seek an outlet, and would cause mineral solutions and metallic vapours to rise up through cracks or vents, hence the pipe-like vertical ore bodies.

Focke of Schneeberg-Neustaedtel, Germany, in a private report on the property of S.A. Minerals, Ltd., in 1933, stated that in view of the pipe-like form of the ore bodies, which in some cases have been proved to a depth of over 100 metres, the origin of the ore bearer, is presumably to be looked for far below. Like Schoch he presumed sulphide gases to have ascended through fault fissures and cracks. He maintained that this fact also explains why the ore bodies generally show a diminishing ore content from the centre to the outside, and that, generally there are no distinct limits between the ore body and the country rock. This report contains various interesting assays which will be referred to later.

Other reports on these deposits are by Dr. F. Behrent, Mr. J. A. Woodburn and the late Mr. A. L. Chambers.

It will be seen that all investigators who have inspected the property since the late Dr. Wagner's visit disagree with him, and oppose the theory of " Magmatic segregation in situ ". Wagner's work was, however, carried out when the deposits were opened up to a depth of not more than 96 feet in the No. 4 ore body, and all the other

shafts were very much shallower. The writer must also admit that at such shallow levels as those exposed during Wagner's visit in 1923, the ore does not by any means look promising and occurs in a streaky manner admixed with gossan. This streaky nature seems to be due to the solvent action of acid solutions along the vertical and horizontal joints.

To-day the No. 1 ore body has been opened up to almost the 400 feet level, and all present underground work reveals the fact that such ore must have come from below after the consolidation of the country rock.

Geology of the Area.

General Geology.

The general geology of the area is shown on Sheet 12 (Pilandsberg) by A. L. Hall and W. A. Humphrey. For a detailed geological map of the major portion of the farm Vlakfontein No. 902 the reader is referred to Wagner's Memoir 21, entitled "On Magmatic Nickel Deposits of the Bushveld Complex".

A geological map of the area and surrounding country of the nickel deposits has been compiled by the writer from data obtained from maps previously published by the Geological Survey. This map is given in this report. It will be useful to refer briefly to the geology of this portion of the Bushveld Complex.

The gossan outcrops are confined to the marginal basic rocks of the norite zone. This zone occupies a broad stretch just west of the Pilandsbergen around which it sweeps with a strike roughly parallel to the outcrop of the outer fringe of the Pilandsberg Eruptive. On the west it is bordered by intermittent broken up Magaliesberg quartzites with altered shales. The contact between the Magaliesberg quartzites and the norite is sharp. The basal portion is occupied by a peripheral zone of diabasic rocks.

In this part of the norite zone gossans have been found as far north as Groenfontein No. 302 and as far south as Vlakfontein No. 902. The latter is the farm to which mining is confined at present.

Only a few intermittent streams are in this area, and these are dry for the greater part of the year.

Outcrops are by no means abundant, the area being covered over the greater part by deep soil, the well-known turf, which has earned a bad reputation owing to the impassibility of its roads after rain. In the winter, however, the roads are hard and good.

The vegetation over this area consists of scanty grass on the lower lying belt, and bush on the koppies.

The rocks in this norite belt are somewhat varied, ranging from a diallage norite on the top to a highly differentiated bronzitite belt below. Occasional xenoliths of quartzite and hornfels occur on the farms Vlakfontein No. 902, Bakhoutrandjies No. 1039, Tweelaagte No. 180, Vogelstruisnek No. 602 and Davidskuil No. 142.

In the lower bronzitite horizon in which the gossans occur, there is clear evidence that the magma must have been fluid for an abnormally long period, thus having afforded the opportunities for crystallisation differentiation on a large scale.

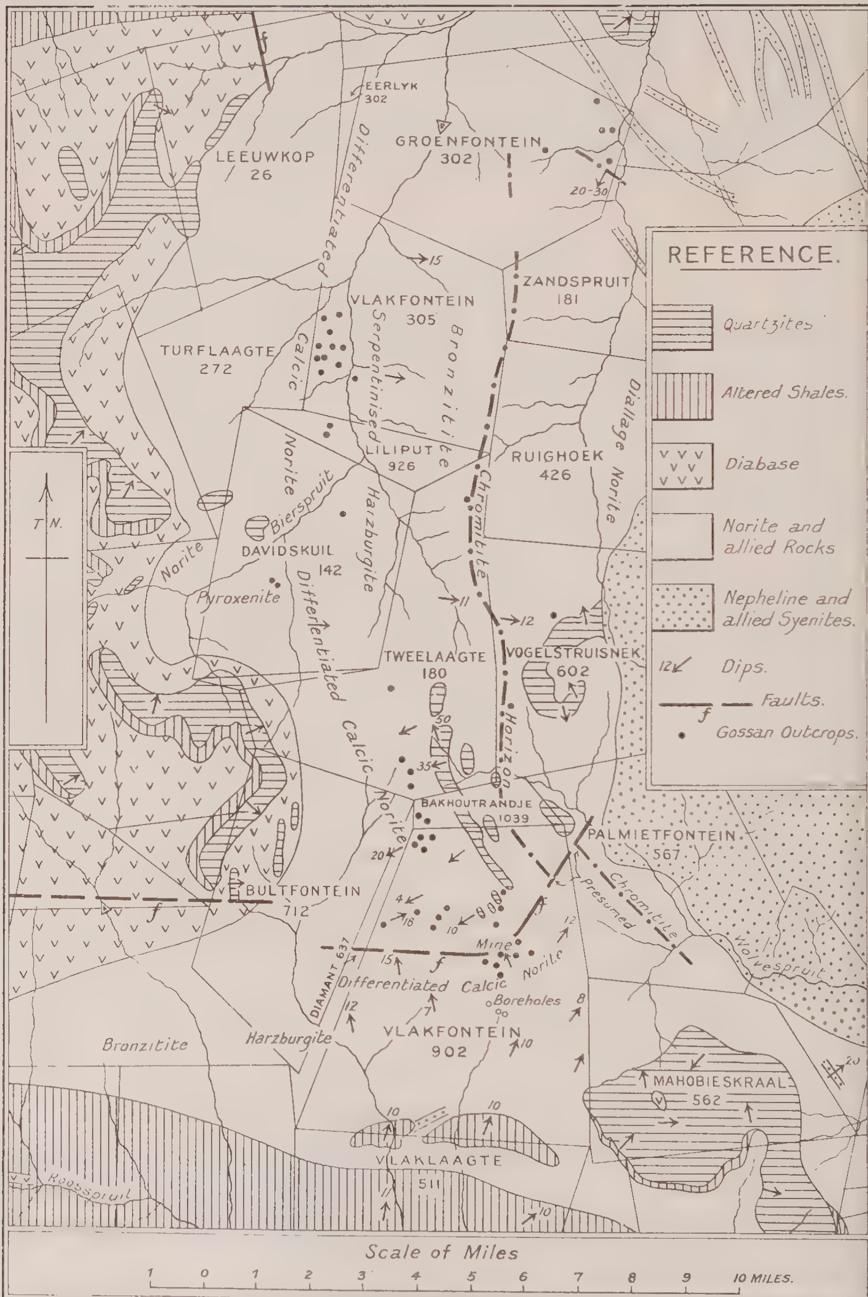


Fig. 2.—Geological Map of the Area West of the Pilandsbergen.

It is worthy of mention here that marked differentiation is recorded from sulphide bearing magmas of basic composition, e.g. Sudbury, Insizwa, etc.

In the vicinity of the Pilandsberg the bronzitite zone exhibits much more pronounced features and forms a series of pseudo-stratified rugged hills, while the lower bronzitite horizon gradually fades into turf towards the base of the Magaliesberg quartzites and shales in the west. In the turf only occasional outcrops are evident.

As has been stated above this lower zone is marked by its highly differentiated rocks. Anorthosites, anorthositic norites, serpentinised harzburgites, and occasional veins of graphic granite occur. The lenses of anorthosite and anorthositic norite seem to be confined to a definite zone, about 1½ mile in breadth, in the bronzitite. Associated, above and below this zone of anorthositic rocks, serpentinised harzburgite occurs in lenslike outcrops, seldom exceeding 400 yards in length and 100 yards in breadth.

The contact between these various differentiates and the bronzitite is not always sharply defined, and the presence and extent of such rocks can only be ascertained by the rubble in the turf.

In the middle of the farm Vlakfontein No. 902 there is a change of strike of the rocks from an east-westerly direction to a north-north-westerly direction. By careful mapping on a large scale Wagner located a curved fault which traverses the farm, changing its strike from a N.E.-S.W. direction in the north-eastern corner of Vlakfontein No. 902, to an E.-W. direction near the centre of the farm.

The bronzitite is a dark brown rock, and when good outcrops occur displays jointing in two directions at right angles to each other. The major joint system runs in an east-westerly direction south of the above-mentioned fault, and changes correspondingly with the change of strike affected by faulting on the opposite side of the fault.

Occasional minute specks of sulphides are visable in freshly fractured bronzitites even in samples taken at a considerable distance from the ore bodies.

Most of the gossan outcrops so far located are chiefly confined to the vicinity of the differentiated calcic norite zone, but there seems to be no genetic connection between the gossans and the anorthositic norite as Wagner postulates.

The dips of the rocks are mostly towards the Pilandsberg at a very low angle, and very seldom exceed 25°.

A Chromitite seam showing outcrops in places occurs in the area and can be traced from the farm Palmietfontein No. 567, through the farms Vogelstruisnek No. 602, Tweelaagte No. 180 and Vlakfontein No. 305, right up into Groenfontein No. 302. The S.A. Minerals, Ltd., have opened up the deposits on the farm Groenfontein No. 302 along a strike of over 1,000 yards at intervals of about 30 yards. The strike of the chromitite is here in a N.W.-S.E. direction and the rock occurs as three well defined seams. These vary in thickness and the lowest seam has an average thickness of about three feet and the dip varies from 30° to 40° in a south-westerly direction. The two seams above this one are much thinner and are separated from

the lowest seam by pyroxenites at a horizontal distance of 15 yards and 250 yards respectively. It is noteworthy that just below the upper seam of Chromitite a well defined seam of magnetite occurs.

A thin hortonolite dunite lens occurs just below the upper chromitite seam on this farm, but no platinum assays are available.

Assays by Mr. T. R. Simpson, metallurgical chemist to S.A. Minerals, Ltd., of the chromitite are following:—

Partial Analysis of a Composite sample of the Lower seam:—

Chromic oxide	44·0 %
Iron	18·6 %
Silica	7·2 %
Phosphorus pentoxide	0·008 %

Assays for Chromic oxide only, and taken at various parts of the thickest lower seam, range from 37 % to 52 %.

A dump of handpicked ore with an estimated toonage exceeding 100 tons has been packed up. An average sample of this ore was analysed by Mr. T. R. Simpson, and the result is the following:—

Cr_2O_3	46·40 %
Al_2O_3	20·43 %
Fe_2O_3	0·88 %
FeO	23·68 %
SiO_2	4·11 %
P_2O_5	0·009 %

A very large tonnage of this grade of ore seems to be available under suitable mining conditions.

Local Underground Geology.

The main rock-types encountered in the mine so far are bronzitites and harzburgites which dip at a low angle in a northerly direction. These two rock-types grade into each other and the contact can be defined within a few inches. No signs of an intrustive contact are evident and the harzburgite is clearly a differentiated product of the parent rock.

Pipelike ore bodies, which grade from a disseminated ore on the periphery to a massive sulphide in the centre, cut across the rock structure. Sometimes the contact between the massive sulphides and the rock with disseminated sulphides is sharp and well defined.

The ore bodies are composed of—

(*a*) massive sulphides,
(*b*) disseminated ore, and
(*c*) ore bearing pegmatite, which contains besides the silicates, sulphides, pockets of chromite and biotite mica.

These three components will subseqeuntly referred to as the "ore magma"

Graphite occurs in the ore as well as in the country rock and its presence is probably due to the assimiliation of graphitic shales by the magma.

Jointing is very well pronounced in an E.-W. and N.-S. direction.

Minor faults and slips are quite frequently encountered. The slips show well developed slickensided surfaces.

Very thin basic dykes have been encountered in the No. III and No. IV workings. These cut the ore bodies and do not seem to be connected with the emplacement of the ore.

Occasional vertical or steeply inclined graphic granite veins cut the rock structure, and there is definitely an intrusive relation between these and the country rock.

Mineralogy of the Ores.

This chapter is only added to give a general idea as to the mineralogical constitution of the ore. The writer has not yet done enough microscopical research work to go into great detail. The data published has been obtained by a study of sections belonging to Dr. D. L. Scholtz, and also from information gathered from previous publications on Vlakfontein.

The three predominating sulphide minerals in every ore body opened up at present are pyrrhotite, pentlandite and chalcopyrite, and their paragenetic sequence seems to be in the order given.

In some ore bodies on the shallower levels marcasite is the predominating sulphide and pyrrhotite is absent, or is present only in minute quantities. Whether this marcasite is a product of supergene alteration or of magmatic origin is a question not discussed in this report, although it may be stated that marcasite has not been found to occur below the 100 feet level in any shaft.

The pyrrhotite is the most abundant sulphide and is found in large massive bodies. In this pyrrhotite the pentlandite occurs both as primary and secondary ore; the primary as isolated crystalline masses with a pronounced octahedral cleavage, and the secondary pentlandite as exsolution lamellae and veinlets in and around the pyrrhotite crystals.

In the *Journal of Economic Geology*—1927, pp. 288-299, W. H. Newhouse published his experiments on the pyrrhotite-pentlandite relations by comparing artificially obtained products with those in nature. He came to the conclusion that pyrrhotite crystallises in the presence of pentlandite, and takes up the nickel but remains unstable under such conditions, and at a certain temperature the unstable solid solution of pyrrhotite containing the pentlandite breaks down and small lens-shaped masses of pentlandite are formed within, and along the border of the pyrrhotite crystals. He concludes that these blade or lens-shaped masses of pentlandite have been formed in nature as well as in artificial products, by the unmixing of an unstable solid solution.

Pyrrhotite is a mineral which is generally accepted to be of magmatic, i.e. of high temperature origin, and the close association of pentlandite with this mineral also points to its formation at high temperature.

The Chalcopyrite occurs as small massive portions and veins in the pyrrhotite-pentlandite association and is certainly later in order of crystallisation, which does not however prove that it is not genetically related to the pyrrhotite and pentlandite.

A sample of massive chalcopyrite-rich pyrrhotite from the No. 1 ore body has been polished, and the chalcopyrite is seen to occur as veins that cut across the other sulphides and from the larger veins minute stringers branch off in all directions. Occasionally the veinlets zig-zag through the pyrrhotite crystals. The only conclusion drawn from macroscopic evidence is that this zig-zag route of the chalcopyrite veinlets is due to its replacing pyrrhotite crystals along the prismatic cleavages, which are at an angle of 60° theoretically, and which are also revealed by the angle of the chalcopyrite stringers on the polished surface.

The Cubanite, which is present in the chalcopyrite, can be looked upon as a geological thermometer, and can establish the temperature of crystallisation to be either above or below 450°. If the cubanite occurs as regular sharply defined lamellae the temperature of crystallisation must have been below 450°, and if the cubanite occurs as patches and lamellae with irregular outline then the temperature must have exceeded 450°. As regards the Vlakfontein cubanite more cannot be said at present than that both types have been observed, and that the cubanite occurs very sparsely in the chalcopyrite of the ore. It seems thus that some of the chalcopyrite is of magmatic and some of hydrothermal origin. What the proportion between these two is cannot be stated yet, but the larger proportion will probably prove to be of magmatic, i.e. of high temperature origin.

Gold, platinum and silver have been reported but evidently do not occur in the free state. Sperrylite, arsenide of platinum, has been found to be present, but could surely not account for all platinum present.

Many other sulphides occur with the ore but no description of these is called for at this stage.

It may be mentioned that occurring with the ore and coming most probably from the same parent magma are silicates, oxides, etc. These are clearly replaced by the sulphides which indicates a later crystallisation of the sulphides.

The silicates are of a basic type and are chiefly bronzite, plagioclase felspar and biotite mica. These occur in exceptionally large crystals and sometimes the bronzite crystals exceed five inches in length and two inches in breadth. The above-mentioned silicates are essentially of high temperature origin and belong to the orthomagmatic stage of the magma.

Chromite occurs very frequently in close association with the silicates, and crystals of this mineral are encountered which are completely enclosed by the pyroxene crystals. It must be said that most of the chromite occurs in pockets or aggregates with the pegmatitic ore. It is however possible that some of the chromite has been taken up by the ore magma when cuttings across lenses of this mineral, which so very frequently occur in this zone of the norite.

Graphite has been found in the ore as well as in the country rock close to the ore bodies, and its presence seems to be due to the assimilation of graphitic shales. That the graphite is responsible for the localisation of the ore bodies as suggested by Wagner does not seem to be a feasible deduction.

In conclusion it may be mentioned that minerals like morenosite, a sulphate of nickel, and epsomite, a sulphate of magnesium, are abundant in old workings that have been at a stand-still for a long time. These occur as stalactites and incrustations, and form a pretty scene with their bright greenish-blue and white colours. These sulphates are undoubtedly supergene alteration products.

The Ore Bodies.

All the underground workings as far as they were accessible were visited. The company very kindly placed at my disposal as guide, Mr. W. Hooper, the underground manager. Assay-values of samples taken from every accessible horizon of the ore bodies have kindly been placed at my disposal by the company.

The greatest number of ore bodies have been opened up and most mining preparations have been made on Vlakfontein No. 902. The writer was able to inspect the following ore bodies:—

No. 1,
No. 1B (or Rock Shaft),
No. 2,
No. 3, and
No. 4.

The different ore bodies will be described separately. The assay-values are given as obtained by the South African Minerals, Ltd., and appear together with the section through the ore bodies. I wish to take this opportunity to express my gratitude to the South African Minerals, Ltd., for the plans and sections of their underground workings.

The No. 1 *Ore Body.*

This ore body has been inspected right down to the 365 feet level, and is the deepest working in this area so far opened up.

The No. 1 ore body had been followed down by a shaft with intermittent crosscuts to the 200 feet level. From the surface to the 200 feet level the ore body went down vertically but when cross-cutting from the main shaft to the No. 1 ore body on the 300 ft. level it was struck about thirty feet before it was expected. It was then thought that this was a separate ore body with the result that exploratory work started on this level with the intention to locate the ore body No. 1 proper. Massive sulphides were encountered not far away from this mostly disseminated ore body. A winze was sunk on this massive body without knowing its dimensions—the winze remaining in massive sulphides up to the sixty-ft. level. However, when the winze reached the depth of sixty-five feet the edges of the massive ore were exposed on the two opposite sides of the winze. The ore body is here much wider, but the body of massive sulphides is elongated out in an east-westerly direction. The boundary between the massive sulphides and the country rock can be very well defined. The contact rock is a thin band of highly calcified chloritic rock which is seemingly due to hydrothermal action. The country rock on either side is a bronzitite with homogeneously distributed sulphides. The extent of the ore body has not yet been proved; the limit of payability of such disseminated ore can only be determined by assay.

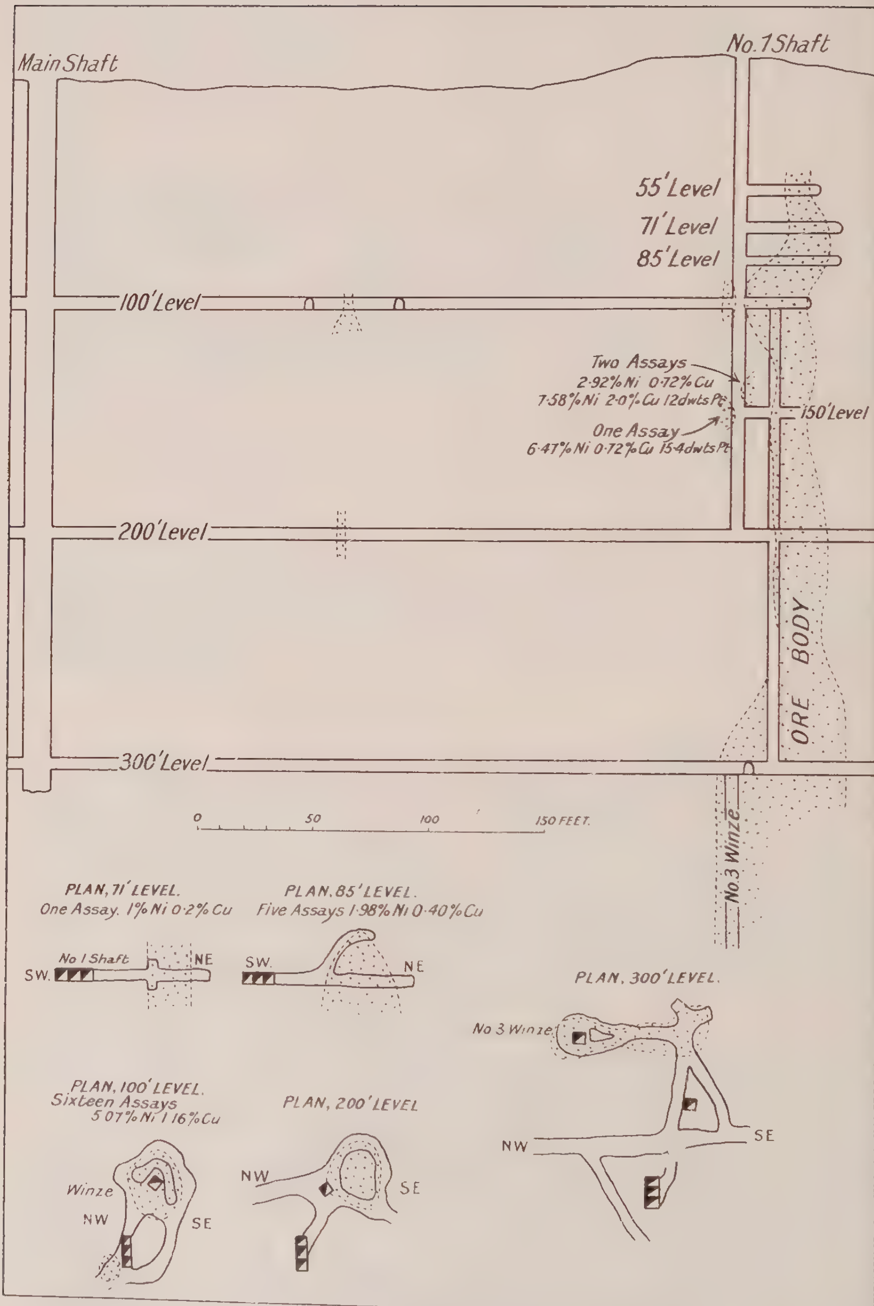
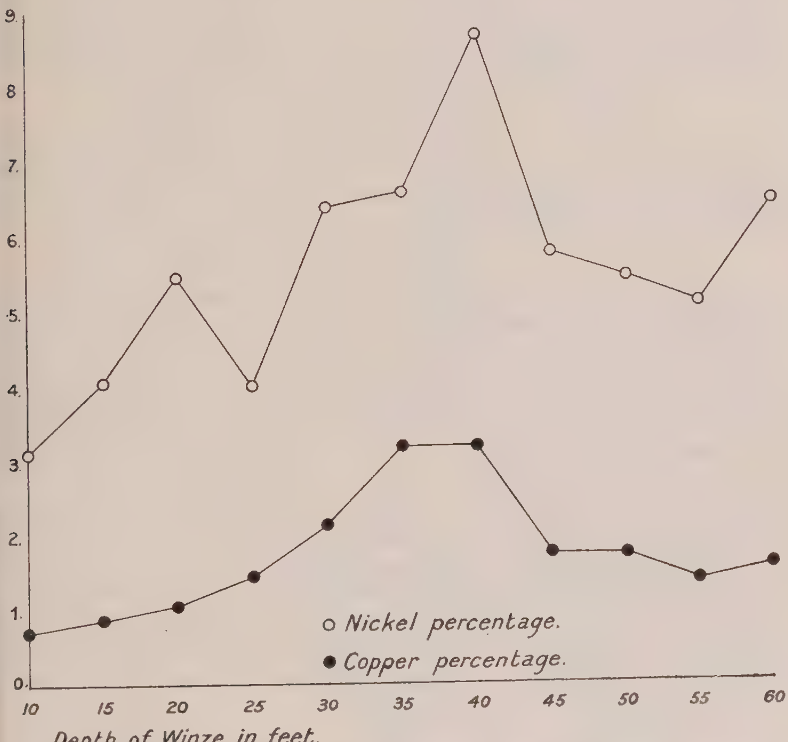


Fig. 3.—Section and Plans of the No. 1 Ore Body.

There is clear evidence that the massive sulphides occur here in nticular mass, the longer axis of which strikes in an east-westerly ection which is the direction of the strike-joints of the country

The assay returns of this winze are remarkably good. The copper centage, as elsewhere, is always less than the nickel. The copper ies are however much more constant than the nickel values as is rly shown in the following graph:—



. 4.—Graph plotted from Assay Values of the No. 3 Winze below the 300 feet level.

Judging from the preceding graph, and from all the other assay urns, there does not seem to be any evidence that the copper tends replace the nickel, as has been found to be the case in the Creighton ine in Sudbury. This assumption can only be proved by subsequent eper mining.

Associated with the sulphides of the No. 1 ore body on all the vels is a pegmatitic rock with exceptionally large crystals of an thorhombic pyroxene, seemingly bronzite. These crystals somenes exceed 5 in. in length and 2 in. in breadth. Plagioclase felspar quite common in large anhedral crystals, and flakes of biotite mica e fairly equally distributed through the rock. Occasional crystals chromite, which are most frequently found in aggregates, are by means uncommon. Disseminated sulphides occur in this rock and e sometimes found to be included or completely surrounded by the g crystals of pyroxene. There is definitely a selective replacement etween the sulphides and this pegmatitic rock, and these two gether cut the country rock in a sharp and well defined manner.

On account of the decrease of the minute specks of sulphides in the country rock away from the massive sulphides, the extent of payability or, rather, the dimension of the ore bodies appears to be determined by the permeability of the country rock by the sulphides, which seems to vary within short distances. This seems to be the only explanation to the irregular bulging out of the ore bodies so frequently encountered.

Worthy of mention here are two small patches of sulphides encountered during shaft sinking below the hundred feet level. On the 130-ft. level, alongside a fault plane a small patch of sulphides is exposed. The only assays available are the following:—

2·92 % Ni	·72 % Cu	0·0 dwt. Pt.
7·58 % Ni	2·0 % Cu	12·0 dwt. Pt.

On the 150-ft. level another small exposure exists, which is seemingly only the edge of a much larger mass. The only available assay of this ore is the following:—

6·47 % Ni	·72 % Cu	15·4 dwt. Pt.

Of these two last-mentioned bodies nothing much can be said because their extent has not been proved yet. Their opening up is awaited with interest.

It might be mentioned here that a thin vein of sulphides has been encountered on the 100-ft. and the 200-ft. level about halfway between the No. 1 ore body and the Main Shaft. This vein parallels the strike-joint of the bronzitite, but is possibly only a small offshoot from the No. 1 ore body.

The cross-sectional area of this No. 1 ore body is approximately 490 sq. ft. on the 100-ft. level, and available data show that on the 300-ft. level the dimensions exceed 700 sq. ft.

The average assay value of this body is 4·73 % Ni and 1·11 % Cu, and the tonnage of ore so far opened up exceeds 24,000 tons. An analysis of a composite sample from the ore taken at various points in the No. 3 winze will give an idea as to the composition of the ore mined from there:—

Nickel	4·25 %
Cobalt	0·36 %
Copper	0·78 %
Sulphur	23·35 %
Silica	20·50 %
Magnesia	8·02 %
Lime	2·08 %
Iron	34·58 %
Alumina	2·66 %
Chromic Oxide	0·23 %
Arsenic	0·12 %

Analyst: T. R. Simpson (Metallurigical-Chemist to S.A. Minerals, Ltd.).

The No. 1B *Ore Body.*

This ore body, which is about 1,200 ft. to the south-west of the No. 1 ore body has been explored to a depth of 151 ft. vertically. The writer was however not able to inspect the ore below the first level, but on this level the ore is chiefly a massive sulphide.

On the 80-ft. level and the 110-ft. level the ore body has been circumscribed. The cross-sectional areas of these two levels show that there is a remarkable increase in the size of the body from the 80-ft. level to the 115-ft. level, the cross-section varying in area from 450 sq. ft. to 705 sq. ft. respectively.

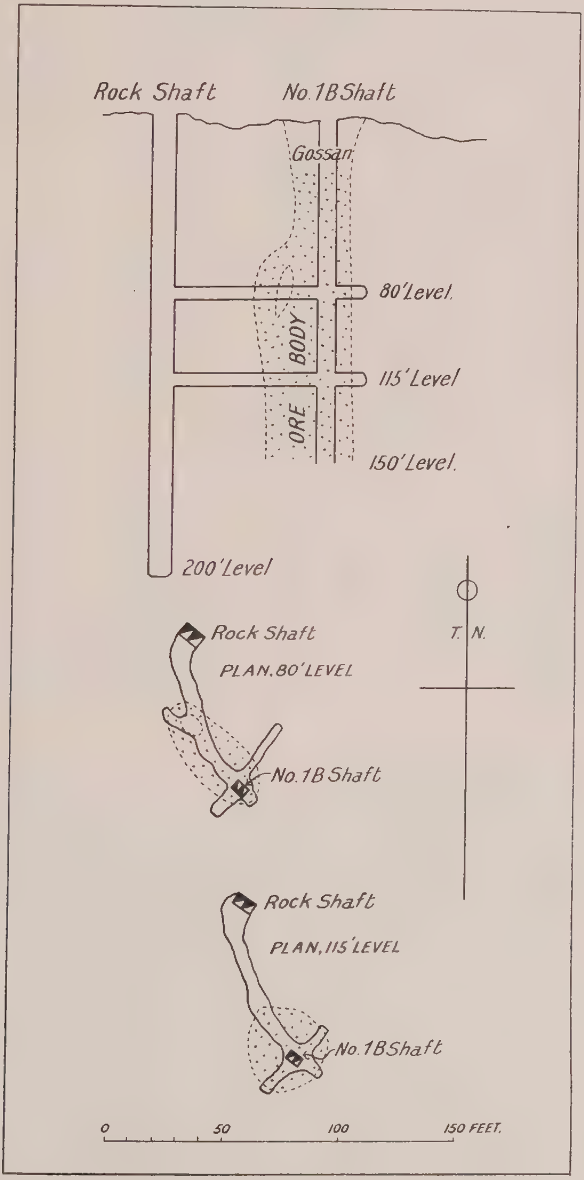


Fig. 5.—Section and Plans of the No. 1 B Ore Body.

The ore has been proved to the 150-ft. depth, but the cross-sectional area has not yet been determined on this level.

The average assay value of this ore body is 4·16 % Nickel, and ·62 % Copper.

The shaft has however been sunk in the ore body, and probably this average assay value is a little too high, although it must be stated that the assay returns of samples taken in the crosscuts are remarkably high as the periphery is reached.

The available tonnage of ore so far opened up is estimated to be over 12,000 tons.

A new shaft has been sunk some 70 ft. to the north-west of the prospecting shaft, from which the ore body will be developed by means of crosscuts.

Assays on the 80-ft. level are the following:—

Crosscuts.	*Distance in ft.*	*% Ni.*	*% Cu.*
North	5	4·35	·42
North	10	4·00	1·40
South	6	2·40	·64
East	5	3·04	1·00
West	5	5·06	·49
West	10	1·10	·70

Assay value from the 115-ft. level:—

Crosscuts.	*Distance in ft.*	*% Ni.*	*% Cu.*
North	6	4·50	1·20
North	12	4·00	1·20
South	5	5·10	1·00
South	10	6·50	·70
East	5	3·20	1·04
West	5	5·50	·50
West	10	4·90	·40
West	15	6·60	·20

The No. 2 Ore Body.

This ore body is situated about 400 yds. north of the No. 1 ore body and is at present being supplied with a new shaft from which the ore is subsequently to be developed by crosscuts. The writer could only inspect the ore down to the 65-ft. level on account of rotted timber and water on the deeper levels. The ore could only be inspected by fracturing the highly tarnished walls of the crosscuts. These are covered by stalactites of morenosite of unique appearance.

The ore is massive near the centre of the body and the proportion of sulphides decreases as the periphery is reached. The relation of the sulphides to the country rock could not be clearly made out. The cross-sectioned area on this level is approximately 1,300 sq. ft.

This same prospecting 2A Shaft has been sunk to a depth of 110 ft. vertically and the ore body circumscribed at that level, the cross-sectional area at this level being approximately 800 sq. ft.

A winze has been sunk on the contact of the ore body with the country rock to a depth of 60 ft., and still remained in ore when operations ceased. Nothing more is known of this body below the 110-ft. level.

The average assay value of this No. 2 ore body is calculated to be 2·33 % Nickel and ·39 % Copper. The indicated tonnage exposed to date is almost 10,000 tons of ore.

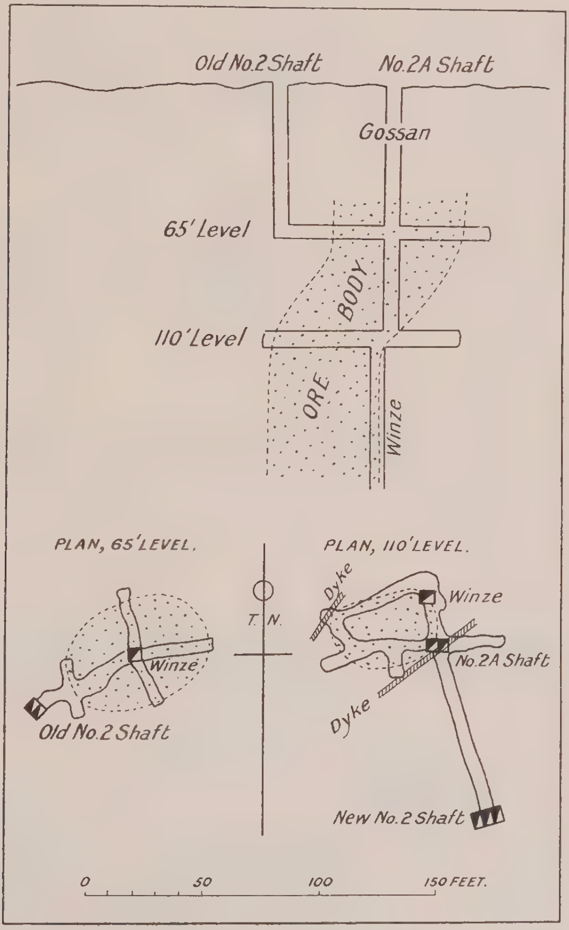


Fig. 6.—Section and Plans of the No. 2 Ore Body.

A marcasite-rich sample from the No. 2 working has been submitted to the Government Chemical Laboratory and Dr. McCrae reported that this contained per ton of 2,000 lb.:—

Silver....................	2 dwt. 3 grains.
Gold	12 dwt. 6 grains.

Worth while mentioning here is that a massive marcasite-rich ore taken by the late P. A. Wagner from the 56-ft. level of the No. 3 workings was reported on as follows by Dr. McCrae:—

Silver....................	4 dwt. 7 grains.
Gold	1 oz. 13 dwt. 4 grains.
Platinum...............	None.

Also two samples of ore from the No. 4 workings weighing respectively 26 and 8 lb. were submitted for assay to Messrs. Johnston Matthey & Co., London, and were found to contain per ton of 2,240 lb.:—

(1) Silver—10 dwt.; gold— 8 gr.; platinum—trace.
(2) Silver—12 dwt.; gold—12 gr.; platinum—trace.

From the No. 2 ore body at the same locality from where the high silver and gold was reported, the late P. A. Wagner took a chalcopyrite-rich sample and this was found by Dr. McCrae to contain:—

Silver....................	1 dwt. 15 grains.
Gold	8 dwt. 7 grains.

From the foregoing it would appear that the gold-content of the ores is very variable, which applies also to the platinum-content; however, the amounts proved to be present would add materially to the value of the ore.

The No. 3 Ore Body.

This ore body lies about 400 yards to the west of the No. 1 ore body, and on the surface indications of ancient workings have been found. Slag found amongst old native kraals on Mahobieskraal probably indicates the locality where these native tribes had their primitive smelters.

When sinking the No. 3 Shaft the gossan was found to dip steeply out of the shaft in a westerly direction. A crosscut on the 65-ft. level was made and the ore was followed by a winze until at 185 ft. down the ore was displaced by a series of slip faults. A winze was then sunk from the 200-ft. level to a depth of 50 ft. and in crosscutting west from it the originally displaced ore body was intersected.

The average cross-sectional area decreased from 615 sq. ft. on the 130-ft. level to 200 sq. ft. on the 250-ft. level.

The writer unfortunately could not inspect the ore body below the 65-ft. level. On this level a thin dyke cuts the ore body obliquely and is definitely intruded subsequent to the emplacement of the ore.

The indicated tonnage exceeds 9,000 short tons, and the average assay value of the ore body is 3·06 % Nickel and ·76 % Copper.

Assay values from crosscuts on the 130-ft. level clearly reveal the fact that the ore is the richest in the centre and decreases in value as the periphery is advanced. There is a decrease of almost 2 per cent. nickel as the margin is reached in the crosscut to the north. The following are assay values from the 130-ft. level:—

Crosscuts.	*Distance in ft.*	*% Ni.*	*% Cu.*
North	5	4·10	1·10
North	10	3·30	1·00
North	15	2·30	·40
South	5	3·10	80
South	10	2·40	1·00
East	5	5·50	1·40
East	9	·80	Trace
West	5	2·40	·80
West	10	2·00	·80
West	15	2·70	·30
West	19	2·30	·30

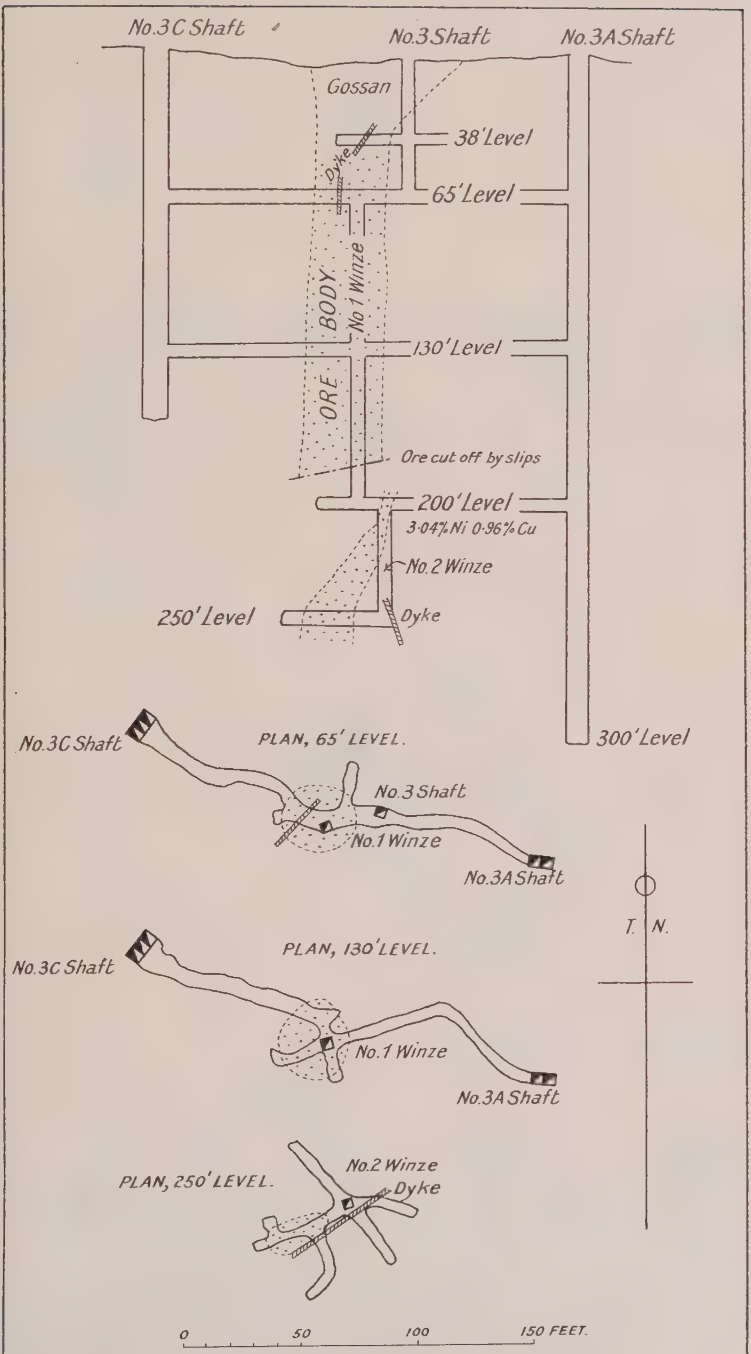


Fig. 7.—Section and Plans of the No. 3 Ore Body.

Assays from crosscuts on the 250-ft. level are less indicative, and also lower in value:—

Crosscuts.	*Distance in ft.*	% *Ni.*	% *Cu.*
West	15-20	2·48	·16
West	20-25	2·00	·48
West	25-30	3·20	Trace
South	0-5	3·28	·40
South	5-8	2·08	·56

The No. 4 Ore Body.

The writer was able to investigate this body on all the levels, except below the 300-ft. level, up to which the shaft is full of water. This ore body supplied the writer with various interesting data.

The ore body is vertical and the ore is of both a massive and a disseminated nature. On the 300-ft. level the relation between the massive and disseminated sulphides can clearly be studied.

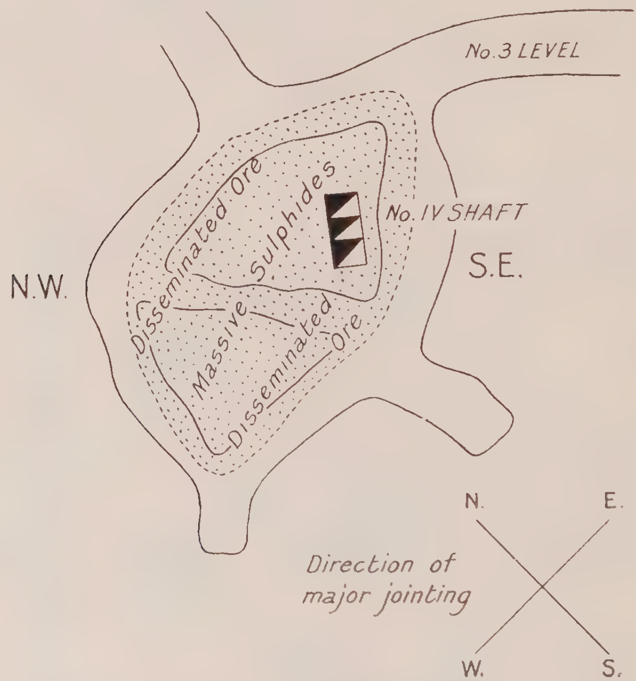


Fig. 8.—Sketch Plan of the 300 feet Level—No. 4 Ore Body.

On Vlakfontein, the mining operations when an ore body is struck are first of all to circumscribe it. In this way the No. 4 ore body is circumscribed and a crosscut has been tunnelled through the ore body. On the junction of the No. 3 level with the ore body massive sulphides are struck. The crosscut through the ore reveals massive sulphides near the centre with a pseudo-jointing in an east-westerly direction. The longer axis of the massive sulphides is here again roughly

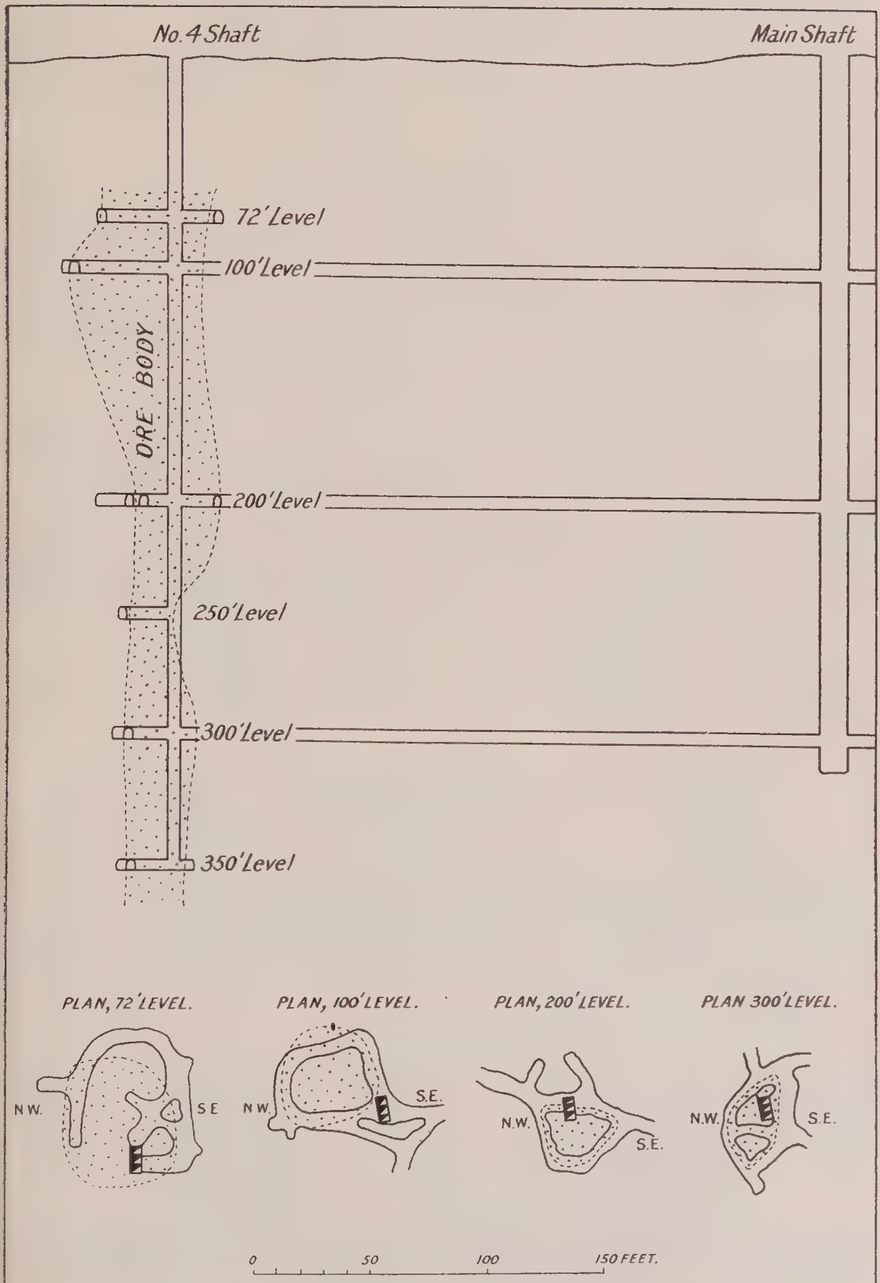


Fig. 9.—Section and Plans of the No. 4 Ore Body.

parallel to the jointing of the country rock. Chloritic material is irregularly distributed near the junction of the massive sulphides with the disseminated ore. The chloritic material always carries minute specks of sulphides. On all three levels the ore is very similar. Mr. T. R. Simpson kindly assayed the following samples taken by the writer. The samples were taken as follows from the 300-ft. level of the No. 4 ore body:—

Massive sulphides in centre of crosscut	5·18 % Ni ·75 % Cu
Massive and disseminated ore halfway between the centre and the periphery of the ore body	4·60 % Ni ·70 % Cu
Disseminated ore from the periphery of the body	5·30 % Ni ·48 % Cu
A sample taken right across the ore body in the crosscut	4·35 % Ni ·94 % Cu

The writer expected the nickel and copper content to decrease as the periphery was approached, but the assays proved just the opposite. The explanation may be that the disseminated sulphides on the edge of the ore body must have contained a higher percentage of pentlandite than the massive sulphides in the centre. This is, however, an exception, and all other assays of ore bodies show a gradual decrease of nickel and copper as the margin is approached. From this one can conclude that the percentage of pentlandite is possibly more or less evenly distributed throughout the sulphides.

A crosscut south on the 300-ft. level which is only partly in ore shows the following values (the samples have been taken at 5-ft. intervals):—

0- 5 ft.	8·32 % Ni	1·12 % Cu
5-10 ft.	5·04 % Ni	1·04 % Cu
10-15 ft.	3·36 % Ni	·64 % Cu
15-18 ft.	4·00 % Ni	·50 % Cu
18-23 ft.	·48 % Ni	Trace

The average assay values of the No. 4 ore body are very promising, and although the ore body decreases in size in depth this is no proof that it will exhibit an abrupt downward termination eventually. Narrowing and subsequent widening has been observed in the other ore bodies and this may be the case here too.

Cross-sectional areas of the ore body at different levels are the following:—

72-ft. level	1,960 sq. ft.
100-ft. level	2,460 sq. ft.
200-ft. level	530 sq. ft.
300-ft. level	350 sq. ft.

In this No. 4 ore body between the 100-ft. and the 200-ft. level eighteen assays show and average of:—

5·53 % Ni
1·37 % Cu

Unfortunately no platinum and gold assays have been made.

Three assays from the 250-ft. level are:—

5·04 % Ni	2·16 % Cu
3·20 % Ni	·58 % Cu
5·04 % Ni	1·68 % Cu

From the 300-ft. level an average of seven assays taken in cross-cuts through the ore body give the following:—

5·14 % Ni ·84 % Cu

From the 315-ft. level there is one assay in which the platinum content has been determined:—

2·56 % Ni ·16 % Cu 1 dwt. Pt.

In none of the Pt. assays made have the elements of the Platinum group been parted.

Assays from the 350-ft. level show a decrease in the copper and nickel content of the ore, an average of four analyses giving the following results:—

1·60 % Ni
·09 % Cu

It may be mentioned here that great variations in the nickel content of the ore of the Sudbury region were observed as depth increased. Statistics show the following average values:—

1895	2·67 % Ni
1900	1·67 % Ni
1905	3·68 % Ni
1907	2·95 % Ni
1908	2·65 % Ni

Experience has taught the Sudbury Mines that average nickel content and tonnage-estimation could not be undertaken until the depth had been thoroughly investigated and properly sampled.

This No. 4 ore body which alternatively shows enlargements and constrictions has an average assay value of 3·92 % Nickel and 1·00 % Copper. The available tonnage proved amounts to over 30,000 tons of ore.

Other Ore Bodies.

Various other ore bodies have been opened up to the sulphide horizon on Vlakfontein No. 902, as well as on the farms Vlakfontein No. 305 and Groenfontein No. 302. Some of these showed very promising assay returns while others did not. These bodies have however not been developed to such an extent as to allow the expression of a definite opinion as regards their exploitability.

The fact remains that the gossans eventually merged into sulphide bodies, and that their payability can only be determined subsequently by careful and systematic exploration.

There exists no reason to believe that the sulphides of these bodies will not contain on the average the same, or very nearly the same nickel percentage as those properly opened up to date.

Worthwhile mentioning here is that over sixty outcrops of gossan are known to occur along a strike of seventeen miles in this area. The approximate positions of most of these are shown on the accompanying geological map.

Genesis of the Nickel-Copper Ore.

When discussing the origin of the Vlakfontein ores two questions have to be answered:

(1) What is the source of the ores? and
(2) How did they come into their present position?

The general sequence of events may be pictured as follows:—

1. *Source of the ores*:—
   (*a*) Emplacement of the Bushveld Magma accomplished in stages as differentiation in depth proceeded.
   (*b*) Crystallisation of the silicates, etc., to form the Bushveld basic rocks.
   (*c*) Differentiation in situ in some of the emplaced portions of the magma in the lower part of the complex including the gravitative settling of the sulphides to the base of the complex where conditions were favourable for concentration.
   (*d*) Crystallisation of most of the silicates (pyrogenetic) accomplished by an increase in the vapour pressure of the residual "ore magma".
   (*e*) Jointing and fissuring of the now already solidified basic rocks.

2. *The present position of the ore*:—
   (*a*) Intrusion of the ore along fissures, intersecting joint systems, and other channels, affording directions of release of pressure.
   (*b*) Crystallisation of the pegmatite associated with the ore and subsequent selective replacement of the silicates by the still molten ore.
   (*c*) Crystallisation at approximately 400°-500° C. of the sulphides.
   (*d*) Hydrothermal alteration along the contact of the ore and deposition of calcite, etc.
   (*e*) Supergene alteration.

The term "Ore Magma".

It will be noted that comparatively *large* bodies of *massive ore* are considered to have reached their present positions by crystallisation at *high temperatures* of offshoots emanating from a supposed deeper reservoir containing certain magmatic constituents both volatile and non-volatile, and included silicates and ore. Having deduced such a mode of emplacement of the ore, it follows that the constituents of the reservoir must have possessed the characteristics of a magma, which is here called the "ore magma".

During the discussion it will be shown that various minerals are closely associated, an observation which forms the reason for referring such constituents to the ore magma, which is taken to consist not only of sulphides, but also to contain solutions, some silicates, etc.

Discussion.

The intrusion of the Bushveld Complex was accomplished by successive injections or flows of the magma. Whether one accepts the granite to be a differentiate or only a later injection would not alter the explanation of the ore genesis. There however remains the fact that every successive flow would impart a large amount of heat to the previously injected portion of the magma. This would then prolong the liquid magmatic period of the lower flow or flows. The marked degree of differentiation in this zone of the norite also points to the fact that the magma must have been fluid for a long period.

Niggli proved that under a pressure of some hundred atmospheres gaseous substances in a melt, whatever the temperature may be, can only exist as solutions.

Unfortunately one is against many uncertainties when proceeding to give some account of the materials that formed the framework of the Bushveld Complex. The time and the order of the major components in the petrogenic cycle has not been definitely proved. There are also uncertainties regarding the extent of the roof of the Complex.

Accompanying and subsequent to the emplacement of the Bushveld Complex floor adjustments took place for the most part in the form of faults. Folding is sometimes locally pronounced, but is as a whole not a prominent feature.

Whatever conditions prevailed in the Vlakfontein area of the Bushveld Igneous Complex at that time, most probably all volatile constituents existed in the form of solutions and were then homogeneously distributed throughout the magma.

After the emplacement of the Bushveld Magma the sulphides, according to the view of Vogd, may be regarded as having separated as an immiscible phase in the form of minute droplets, which, owing to their greater density would tend to gravitate towards the hollows or depressions in the floor of the Complex. Such concentrations would no doubt be facilitated by the coalescence of droplets, and in this manner accumulations of ore together with certain late magmatic residues constituting the " ore magma ", would result. In the meantime the crystallisation and differentiation of the pyrogenetic silicates, constituting the main bulk of the Bushveld Magma, proceeded shortly after the accumulation of the bulk of the ore.

Small pellets or droplets of ore of late arrival were unable to penetrate the now viscous magma in an advanced state of crystallisation, and are now represented by the sparsely scattered sulphide specks so frequently encountered on fracturing fresh specimens from outcrops of rock $\pm 2{,}000$ ft. above the base of the Complex.

With further drop in temperature there would occur a noticeable increase in the vapour pressure of the still liquid " ore magma " surrounded by already consolidated igneous rock, rendering the ore an active intrusive which would exploit such directions as would permit release of pressure.

Due to differential stresses, joints and fissures were formed shortly after the consolidation of the silicate rocks.

The " ore magma " reservoir, being under such a great pressure, would take advantage of such zones of weakness and would be pushed out in these in the same way as an ordinary rock magma would be expected to take advantage of zones of weakness in the earth's crust. Whether the ore magma has been pushed along cracks in an upward direction only is impossible to say because the force of the pressure would act equally in all directions. This factor depends largely on the permeability of the chillzone and the underlying rock, the nature of which is not known. The hornfels of the Pretoria Series which could be expected to form the floor, is a solid and highly impermeable rock, and it can thus be assumed that the major portion of the ore magma has been injected into the direction of least resistance, which would most naturally be vertically upward into the basic rocks.

In the No. 1 ore body it is clearly visible that the sulphides followed a joint, and from conclusions drawn from various other localities it seems clear that the joints were the primary zones of weakness chosen by the ore magma on the release of pressure.

The silicates, which were entrapped in the ore magma are seemingly the source of the minerals composing the pegmatite associated with the ore. The only explanation of the large basic silicate crystals is that these must have resulted from the volatiles retained in depth until crystallisation was far advanced. There is definitely a selective replacement of the basic pegmatitic silicates by the ore, and the writer assumes that the pegmatite and the ore are genetically related for the following reasons:—

(1) The pegmatite and sulphides cut the country rock.
(2) The pegmatite and sulphides grade into each other.
(3) Sulphides have been found included in pegmatite crystals.

Therefore the pegmatite can be referred to the ore-magma.

That the pegmatite crystallised at a high temperature does not seem to be doubtful. The constituent silicates which are chiefly bronzite, plagioclase felspar and biotite are essentially orthomagmatic (in the sense as used by Niggli) minerals.

The ore-minerals are also of a high temperature origin. The cubanite present in the chalcopyrite, which can be regarded as a geological thermometer, is chiefly present as cubanite of the high temperature type, thus indicating a temperature exceeding 450°. It is however possible that some of the chalcopyrite was deposited hydrothermally, but there exists no doubt that the major portion of it is of magmatic origin.

The ore is clearly of magmatic origin and crystallised at a high temperature. The sequence of crystallisation is first the silicates and then the sulphides in the following order: pyrrhotite, pentlandite and chalcopyrite. The sulphides clearly replace the silicates.

Hydrothermal action, especially close to the periphery of the massive sulphides, is occasionally visible. This limited amount of hydrothermal alteration is to be attributed to the mineralisers associated with the ore, rather than to the transport of the ore by hydrothermal agencies. The zone of hydrothermal alteration is too narrow for this to be considered as the transporting agent of the ore.

Whether offshoots from the ore-magma reached the surface at the time of injection, or whether these have only subsequently been exposed by weathering is impossible to say. It is however a possibility that many such offshoots never even reached the present surface level and are still hidden.

Whatever may have taken place, the outcrops of all the deposits take the form of a brightly coloured ferruginous opaline gossan which is due to alterations by agencies from above. These gossans represent the insoluble colloidal residuum left over after the destruction, mainly through the agency of sulphuric acid, of the ore and rocks adjacent to it. The sulphuric acid has been formed by the action of the atmosphere on the exposed sulphides. Morenosite, a hydrous nickel sulphate, and epsomite, a hydrous magnesium sulphate, are abundantly present in workings that have been at a standstill for a long time and occur in minor quantities on old ore-dumps. Their presence can only be ascribed to a supergene alteration.

Of interest to mention here are the veins of graphic granite so frequently encountered in the underground workings. These may be looked upon as magmatic exudations and are evidently not genetically related to the ore-magma.

Thin basic dykes are found to cut through the ore bodies in various workings, but their mode of occurrence and relation to the ore body shows that they are definitely of a later origin.

Summary.

From the foregoing discussion of the genesis the ore is considered to have come from a level lower than that which it occupies to-day, i.e. to have its immediate origin in an ore magma from which it was injected into the country rock along fissures and joints as molten material together with partly crystallised silicates.

Economic Considerations.

The nature and extent of the ore bodies beyond the depths reached by the present mining development still has to be proved. On the basis of the genetic theory propounded it is reasonable to assume that they will extend to much greater depths—probably to the base of the norite. What the form of the ore bodies will be can only be revealed by deeper mining.

The ore proved to the present date amounts to at least 100,000 tons.

Grade of the Ore.

In 1927 Schoch, consulting engineer and Manager of S.A. Minerals, Ltd., showed the total tonnage in sight to be 77,460 tons of an average assay value of 3·54 % nickel and 0·78 % copper.

Dr. Mellor took nineteen representative bulk samples from the No. 1, No. 3 and No. 4 workings and these averaged 3·3 % nickel and 0·59 % copper.

In 1933 Dr. Focke collected representative samples at random from the ore bodies as well as the dumps. His average results are the following:—

Fe %	37·2
Co %	·3
Ni %	3·0
Cu %	·73
gAu/t	·67
gPt/t	·35
gAg/t	19·00

In all Focke's eighteen samples assayed there has been found cobalt, gold, platinum and silver, and the assays show that the precious metals seem to be distributed throughout the ore.

All these average assays seem to agree closely with the present calculations, and on the average the proved ore contains well over 3 % nickel and ·7 % copper.

It is impossible to predict what the grade of the ore will be at deeper levels, but in view of the constancy of the nickel and copper content of the ore proved to a depth of 365 feet, it is reasonable to assume that there will be no abrupt change in the grade of the ore in depth.

The average precious metal content has not been determined, but these metals seem to be present in sufficient quantities to enhance the value of the ore.

It is difficult to say what would constitute profitable ore at Vlakfontein, but it can definitely be stated that nickel ores of a much lower grade and probably poorer in precious metals have been worked in other parts of the world.

In Norway ore averaging from 1·4 % to 1·7 % nickel, after having been handpicked, has been worked; and in Germany ore containing 1 % to 2 % nickel was successfully exploited.

In 1917 the grade of ore worked in the more important Sudbury mines was as follows *:—

Mine.	*% Waste Rock Removed by Sorting.*	*% Nickel in Handpicked Ore.*	*% Copper in Handpicked Ore.*
Copper Cliff	not stated	3·52	5·13
Cream Hill	50	2·14	2·91
Creighton	10-16	4·44	1·56
Garson	24	2·40	1·70
Mount Nickel	not stated	2·40	1·20
Victoria	25	1·5-2·5	3·00
Worthington	60	3·00	4·00

The Vlakfontein ore contains less copper on the average, but its nickel content is higher than the average value of the Canadian ore.

Treatment of the Ore.

The South African Minerals, Ltd., are at present interested in this proposition and are erecting a plant which they are confident will

* Quoted from Wagner's Memoir 21, which is according to the Report of the Royal Ontario Ni-Commission.

work profitably. A detailed description of the plant and methods of extraction are not called for at this stage, but the scheme to be adopted is shortly outlined in the following:—

(1) Preliminary roasting to reduce the sulphur content.
(2) Smelting of the partially roasted ore in blast-furnaces. The precious metals are automatically concentrated in the matte.
(3) De-ferration of the matte in a converter to produce a rich matte containing about 80 % nickel.

The final matte has to be sent overseas for refining.

Uses of Nickel.

Nickel is a hard, lustrous, silver-white metal taking and retaining a brilliant polish. It is used for a great variety of purposes, the most important of which are the following:—

(1) Mainly in the form of alloys with other metals, e.g. nickel-copper, and nickel-silver ,alloys;
(2) for the production of nickel- and alloy-steels;
(3) used for cooking utensils, evaporating basins, crucibles, etc., due to its non-corrosive properties;
(4) for coating iron, steel, brass and zinc; and
(5) as an anode in storage batteries.

A large number of small articles of general utility are made of nickel, and new uses are constantly being found for the metal, but the demand for it is limited.

Chemical compounds of nickel of industrial importance are not numerous. The oxide is used in the manufacture of glass, in the ceramic industry, and for a few minor purposes; the oxide and some other compounds are sometimes used as catalyzers; nickel-sulphate and the double sulphate of nickel and ammonium are largely used in nickel electro-plating.

During the Great War enormous quantities of nickel-steel were used for the production of armour-plate, projectiles, gun-shields and other articles of military and naval equipment. The demand will probably not be as great in the near future as it was during the war.

General Observations.

(a) Accessibility.

The nearest railway station is at Boschhoek which is about 18 miles away in an east-east-southerly direction. From this station a good road is made up to the mine, and with the present abundant tar obtainable from the Pretoria Steelworks such a road could be made to last a very long time.

On the farm Sandriviierspoort No. 747 a bridge has recently been built over the Wolvespruit, thus rendering the river passable at all times of the year.

A railway line could be connected with the main line within a distance of 15 miles from the mine, which should greatly facilitate the transport of heavy material, which is at present done by Sentinel Steam Lorry.

(*b*) *Labour.*

Enough native labour should be easily obtainable because the country is well populated and there is a large kraal on Mabieskraal No. 620, about 10 miles north-west of the farm Vlakfontein No. 902. On the farm Vlakfontein No. 902 a small location is situated about one mile to the south of the mine.

Vlakfontein seems to be an ideal spot, with the suitable climatic conditions for European labourers who are in the preliminary stages of phthisis and are not fit to do work in phthisical mines. The Potgietersrust Platinums, Ltd., on the farms Kroondal and Klipfontein employ such men.

(*c*) *Water supply.*

Boreholes have been sunk at various places to obtain water without result, until just recently a borehole has been sunk on a spot selected by Mr. Frommurze, geologist to the Geological Survey. At a depth of 145 ft. water has been struck, and a test which lasted fifty hours, proved the supply to be at a rate of not less than 2,500 gallons per hour. This can keep the mine running and also supply the needs for domestic purposes. Should the mine extend far beyond its present limits then a few other boreholes will have to be sunk.

A second reserve borehole has now been sunk in the vicinity of the last mentioned one, and similar quantities of water have been obtained. A third borehole 600 yards away from the above-mentioned sites yields 1,700 gallons per hour. These three boreholes are more or less 200 feet below the level of the mine and the water is pumped into tanks on a koppie from where it gravitates to the mine.

(*d*) *Timber.*

For shaft timbering and large supporting blocks the timber will have to be obtained from dealers in Pretoria or Johannesburg. Bluegum trees which form an ideal support seem to be very sparsely distributed in the vicinity of the mine and will have to be obtained from distant plantations.

The flanks of the Matlapynsberg in the west, the Pilandsberg in the east, and other mountains in the vicinity of the mine are all well wooded and could be a source for timber to be employed for the purpose of stope-filling.

(*e*) *Fuel.*

Coal and Coke can only be obtained from the nearest coalmine, which is at Witbank.

Petrol, crude oil, etc., is at present conveyed by lorry from Boschhoek, and the pilot electric plant is driven by a crude oil engine. Very many difficulties would be overcome by a railway line from Boschhoek to the mine.

A power station is being erected, and will be complete in a few months.

Exploration.

The existence of unknown bodies is so strongly suggested as to call for further exploration. From the mode of occurrence and the origin of the ores it follows that the chief prospecting must be directed to the base of the norite.

The location of the parent ore magma underground would however present a problem of very great, probably insuperable, difficulty.

Geophysical methods seem to be the cheapest and the most indicative method which could be carried out on such a proposition. The seismic method might in favourable cases indicate the depth of the parent ore magma. Gravity methods could however pick up ore-indications through an enormous thickness of overlying rock, and this method would seemingly give the best results.

Prospecting by drilling would only be very haphazard on account of the depths involved and the large number of boreholes required would be prohibitively expensive.

Geophysical results could however be tested subsequently by one or two boreholes which would in turn prove the thickness of the ore below, and also an idea of its average metal content.

Due to the irregularity in outline of the pipelike ore chimneys the size of these in depth could only be estimated by gravity methods.

In view of the abundant sparsely distributed outcrops, and the small proportion of the area and gossans that have been closely investigated, there seem a fair probability that further discoveries might follow careful and systematic search on the lines above indicated.

Conclusion.

Transport, labour, timber, fuel, water-supply, etc., are already accessible and if the supplies need increase then these could soon be made available. The geographical position of the area is by no means too unfavourable—much more favourable than that of many other mines in the Northern Transvaal.

Of nickel the already available world supplies are abundant; so much that at Sudbury only a few of the mines are in commission. These alone supply the world with 90 % of its nickel, the balance coming chiefly from New Caledonia.

The steel-works, ammunition factories and other minor important consumers in South Africa may need nickel, but these internal needs of South Africa in nickel could hardly keep a new field going. Export would be essential to economic exploitation, and according to the management export markets have already been obtained overseas.

The by-products of the ore should greatly enhance the value of the ore.

The Sudbury nickel deposits seem to be of the same nature and origin as those of Vlakfontein. The Canadian deposits have however much larger pipes or ore-chimneys, and should the Vlakfontein pipes widen out in depth to such dimensions that these are economically exploitable then there seem to be no reason not to expect a long life for the mine.

The sulphides of Vlakfontein and also those of the Merensky Reef contain on an average a higher proportion of nickel than those of the Sudbury sulphides. From this one can assume that the possible average nickel content of the sulphide in the Bushveld norite is higher than that of the Sudbury intrusive. Therefore exploration by methods suggested elsewhere would possibly reveal ore of a similar grade to that mined at present on Vlakfontein.

The present grade of the ore indicates that there is no reason why the nickel deposits should not be profitably worked. The future of the successful exploitation of these deposits will depend upon whether sufficiently large tonnage can be proved beyond depths at present reached in mining.

Other Known Occurrences of Gossan Outcrops in the Bushveld Complex.

Opaline gossans of the same type as those found on Vlakfontein and the adjoining farms are known in other parts of the norite zone, and occur geologically on roughly the same horizon as those of Vlakfontein.

Klipfontein No. 482, *District Pretoria.*

Old shallow and fallen in workings on gossans occur in the south-western portion of this farm. These have been prospected by previous unknown inhabitants. Green copper stains have been found on the gossan, but no trace of nickel could be detected. This farm is situated about 12 miles north-west of Pretoria.

Hartebeesfontein No. 5, *District Pretoria.*

Wagner mentions, in his well known book "The Platinum Deposits and Mines of South Africa", gossans of the same type as those found on Vlakfontein on the northern portion of this farm which is situated about 20 miles west-north-west of Pretoria.

Rooikoppiesfontein No. 123, *Marico District.*

Opaline gossans with small isolated crystals of sperrylite and small amounts of nickel have been located on this farm which lies about 50 miles west-north-west of Vlakfontein No. 902.

Derde Gelid No. 141, *Lydenburg District.*

Gossans resembling those of the Vlakfontein area with traces of nickel and copper occur on this farm, but these seem to be on the diabase horizon.

Whether these above-mentioned gossans will invite attention remains to be seen. Their opening up, however, will be awaited with interest.